Water Use and Impacts Due Ethanol Production in Brazil

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Abstract

Ethanol production from sugar cane crops uses significant amount of water in the agricultural and industrial processing phases. Most of the sugar cane plantations in Brazil rely on natural irrigation complemented by partial ferti-irrigation, carried out mainly to manage water wastes, limiting their production to regions where reasonable rainfall index occurs. Sugar cane processing to ethanol uses water collected mainly from surface water flows and, in few cases, from underground natural reservoirs for many different activities and it become contaminated with organic and inorganic pollutants.

Water availability is not a problem now or in the mid-term in a water rich country like Brazil, except in some specific regions where the amount of rainfall is not the most recommendable for sugar cane growth. Nevertheless, due the increasing demand for ethanol and the high prices paid for it sugar cane crops tend to expand to regions where natural irrigation needs to be complemented with artificial water spray. On the other hand water pollution caused by application of fertilizers and agrochemicals, by soil erosion, by cane washing, by fermentation, by distillation, by the energy producing units installed in the mills and by other minor sources of waste water is a major concern due the large size of such agro-industrial activity. The paper describes agricultural and industrial activities involved in ethanol production trying to quantify the amount of potential pollutants that are sources of water contamination and provides description of measures commonly used to mitigate such contamination and the ones used to clean waste water. Waste water quality returned to soil and to surface water flows is regulated by the government and such regulations are properly described and discussed. Suggestions on how to improve the quality of waste water above the present level imposed by regulation are also discussed. In particular, the main source of water pollution, stillage, is examined in detail as potential source of energy and other products while its intensity of contamination is reduced.

1. Availability and use of water in Brazil

1.1 Introduction

Fresh water is distributed(Freitas, 2002) around the world as follows: 76.7 percent in glaciers and ice tables; 22.1 percent in water tables; and 1.2 percent in surface in surface waters. Brazil stands out for its great abundance of water resources both on the surface and in water tables. Table 1 compares the figures of Brazil to the world average supply (mean runoff of basins) and consumption of surface water. Brazil has 50,000m^2 of its surface covered by fresh water (rivers, lakes).

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Table 1: Surface water supply and consumption, Brazil and the world

	Supply (1)		Consumption (2)	
	km^3/year	m^3/inhab.year	km^3/year	m^3/inhab.year
Brazil	5,740	34,000	55	359
World	41,281	6,960	3,414	648

Notes: (1) Mean runoff, 2000
(2) Consumption as evaluated in 1990

As to water tables, the Guarani Aquifer covers a total area of approximately 1.2 million km^2 – 839,800 km^2 of which in Brazil's Center West and South regions. It stores around 40,000 km^3 of water (which is equivalent to the world's total annual runoff). Because of both its huge availability and it is low per capita use of water, Brazil is in a privileged position to plan the multiple uses of water in a sustainable way.

The space distribution of surface water resources and population causes only a few regions to appear as "critical" (supply below 1,500m3/inhab.year). According to a preliminary analysis conducted by the National Water Agency, the main utilization conflicts (with different regional emphases) should consider: electricity generation; irrigation in agriculture; waterways development; human supply; leisure; and special cases of borders, floods and droughts. If well-grounded, the billing for use of water that starts being implemented in some regions of the country may favor the adoption of appropriate handling practices for the various applications, particularly the use in irrigation projects.

The production of sugar cane and ethanol requires water, which could lead to a depletion of fresh water resources. The water supply to water use ratio for Brazil as a whole was calculated at 1% in 1995, and this figure is projected to increase to 3-5% in 2075, dependant on the irrigation scenario (Berndes, 2002). Water use refers to the withdrawal of water for irrigation and the industry and households. A ratio of 25% or higher is generally an indicator of water stress. For comparison: the water supply to use ratio in Germany was calculated at 38% in 1995 and 112-138% in 2075. These figures indicate that Brazil has one of the lowest water supplies to water use ratios in the world. However, regional water shortages occur. Brazil can be divided into eight major water basins, see Table 2.

The most important sugar cane producing regions in Brazil are situated in the North and Northeast basin, San Francisco basin, the East Atlantic basin and the Paraná-Paraguai basin (FAO, 2004). The focus in this paper is on sugar cane production in the south of Brazil, which relates mainly to the Paraná-Paraguai basin. According to the FAO, there is sufficient water in the Paraná-Paraguai basin as a whole to supply all foreseeable long term water requirements from agriculture, households and industry (FAO, 2004). The same goes for most of the other water basins. However, local water shortages may occur as a result of the occurrence of various water using and water polluting sectors (agriculture, industry) and/or cities and/or in case there of unregulated use of water and unregulated dumping of wastewater. Some of these regions include sugar cane and ethanol producing regions, an example is the Piracicaba river basin in São Paulo (FAO, 2004).

Table 2: The eight major water basins in Brazil

Basin Name	Main cane producing region (yes/no)	Area ($1000km^2$)	Precipitation (mm/yr)	Evapotranspiration (mm/y)
1. Amazon in Brazil	No	3935	8736	4919
2. Tocantins – Araguaia	No	757	1257	884
3. North and ortheast	Yes	1029	1533	1240
4. San Francisco	Yes	634	581	491
5. East Atlantic	Yes	545	321	246
6. Parana-Paraguai	Yes	1245	2140	1657
7. Uruguai	No	178	279	148
8. Southeast Atlantic	No	224	312	177
TOTAL		8547	15158	9761

Source: FAO, 2004

1.2 Irrigation

Although water does not seem to be a limiting factor today, the use of irrigation in agriculture is very small in Brazil. In most of the Brazilian territory, the agriculture used is dry farming: crops are grown depending exclusively on natural rainfall. In some regions, especially the *cerrados*, or savannahs, the total rainfall in the rainy season is enough for the development of agriculture. This is in spite of the frequent occurrence of successive dry days during the rainy season; which affects the development of crops and the final productivity.

Irrigation in Brazil's crop areas took up only 2.9Mha in 2002 (FAO, 2004). More recent estimations point to 3.3Mha, including all systems (drainage control on the surface, or using standard sprinkling, central swivel systems or localized irrigation). This corresponds to only 1.2 percent of the world's irrigated areas (277Mha).

Even though the use of water for irrigation is very little in Brazil, it should be pointed out that the use efficiency (relation between the water coming to the crops and the water withdrawn from sources) is low: 61 percent on average. This results from the use of surface irrigation for 50 percent of the total water in Brazil.

1.3 Water Use for Sugar Cane and Ethanol Processing

1.3.1 Introduction

For the production of sugar cane and ethanol two main types of water use can be distinguished:

- Water use for cane production. The evapo-transpiration of sugar cane is estimated at ca. 8.0-12.0 mm/t cane and the total rainfall required by sugar cane is estimated at 1500-2500 mm/y, which should be uniformly spread across the growing cycle (Macedo, 2005). For comparison: the annual rainfall in São Paulo is roughly 1000-2500 mm/y. These figures indicate that water can be a limiting factor for sugar cane crop production under certain conditions in São Paulo. To what extend evapo-transpiration from sugar cane production contributes to regional water shortages is unknown. However, the use of rainfall for crop production is generally considered as acceptable.

- Water use for the conversion of cane to ethanol. Large quantities of water are used during the conversion of cane to ethanol. The total water use is calculated to be 21 m^3/t cane, of which 87% is used in four processes: cane washing, condenser/multijet in evaporation and vacuum, fermentation cooling and alcohol condenser cooling. Note that the water use for cane washing (5 m^3/t cane) is being reduced by the replacement of wet cane washing with dry cane washing. The net water use is much lower, because most of the water is recycled (see Table 5). As a result of legislation and technological progress, the amount of water collected for ethanol production has decreased considerably during the previous years. It seems possible to reach a 1 m3/t cane water collection and (close to) zero effluent release rates by further optimizing and reuse of water use and recycling (Macedo, 2005). The World Bank reports a target value for wastewater release of at least 1.3 m^3/t cane and an achievable rate of 0.9 m^3/t cane (WB, 1998).

1.3.2 Water use for cane production

The use of irrigation is being investigated in Brazil for sugar cane, on a very small scale. Taking full advantage of the natural climate conditions while implementing irrigation systems – for full, supplementary or salvage irrigation – may lead to interesting cost-benefit rations in some cases.

Irrigation in sugar cane production is more widespread in Northeast (Anselmi, 2004). It also displays gradual growth in the Center-West and some areas in the Southeast, especially in Rio de Janeiro, Espirito Santo and west of São Paulo. “Salvage irrigation” is used after the planting of sugar cane in order to ensure sprouting in long periods without rain. “Supplementary irrigation” with different blades at the most critical of development stages is used in order to mitigate any shortages of water; and irrigation is used throughout the cycle, in relatively small areas.

Practically all of the sugar cane produced in São Paulo State is grown without irrigation(Matioli, 1998) based on economic analysis that were conducted considering full irrigation and productivity gains. The sugar cane harvesting season and the increase in longevity of the sugar cane crop, among other factors, have an influence of the feasibility of irrigation. The growing demand for the incorporation of new sugar cane areas in the Center-South region of Brazil has lead to the exploitation of regions having higher water deficits. In these cases, irrigation can be economically feasible, especially using more efficient methods.

For the most part, it can be said that some of the environmental problems arising from irrigation, and found in many sugar cane and beet crops around the world, do not exists in Brazil. An evaluation provided by EMBRAPA (Rosetto, 2004) rates the impacts of sugar cane crops on water quality as level 1 (no impact).

In general there is sufficient water to supply all foreseeable long-term water requirements in the Centre-South region of Brazil as a whole, but local water shortages can occur as a result of the occurrence of various water using and water polluting sectors (agriculture, industry) and/or cities and the uncontrolled use of water and uncontrolled dumping of wastewater.

1.3.2.1 Legislation on Water Use

To ensure an efficient use of fresh water resources, legislation is being implemented in some regions. This legislation includes the billing of water, for both the agriculture and the industry. In SP, a State Plan on Water Resources (Plano Estadual de Recursos Hidricos or PERH) was made that includes data on and projections of the water demand in SP. Table 3. shows the surface water availability and demand in São Paulo in 1990 and 2004-2007 in various water plans.

Table 3: The availability and demand of surface water in São Paulo

		PERH-1990		PERH-2004-2007	
		1990		2003	
		m^3/s	%	m^3/s	%
Supply	Reference	2105		2020	
	Minimum available flow	888		893	
Demand	Urban	97	24	151	39
	Irrigation	154	44	102	26
	Industry – Total	112	32	137	35
	Industry – Mills	47	13	-	-
	Total	353	100	390	100

Sources: State Plan on Water Resources 1994-1995 and PERH 2004-2007 in Macedo (2005)

The increase in the use of water for the industry (including the sugar cane 25 industry) is limited as a result of the implementation of new legislation that provides for billing of water use.

In brief, there is an extensive legal framework related to water use in Brazil and São Paulo and addition legislation has recently been implemented in Brazil to promote a more efficient use of water, based upon the "user-payer" and "pollutant-payer" principle: the user and polluter pay dependent on the amount and quality of the water collected and released. This principle is applied in all economic sectors in Brazil. There is yet no legislation for waters within SP, such as underground water, and rivers that die within the boundaries of SP. Note that water pollution is discussed in Section 3, but the legislation discussed here is relevant for both water use and water pollution.

Protection of Water Resources and Streams - Possibilities in the sugar cane culture

In most of sugar cane culture cases, places considered permanent preservation areas (APPs) have been left for natural, spontaneous recovery. This has been happening especially over the past few years. The recovery of degraded riverside woods by reforestation activities is still limited to only a portion of the total area,

A survey to evaluate the dimensions and situations of permanent preservation areas corresponding to old riverside woods, involving a large number of mills in São Paulo (Barbosa, 2005) covering owned and leased land (around 750,000 ha), and in many cases, land owned by sugar cane suppliers, is shown below. The results are denoted in % of the sugar cane crop area.

Total APP (banks, springs, lagoons)	8.1% of the sugar cane area
APP with natural woods	3.4%
APP with reforestation	0.8%
Abandoned APP	2.9%
APP with sugar cane	0.6%

The portion having natural woods is important, and the reforested area has grown over the past few years. The importance of implementing programs like that of São Paulo SMA, besides the necessary protection of water streams, has to do with the ability to foster a restoration of the plant biodiversity in the region if the programs follow appropriate criteria.

1.3.3 Water Withdraw for Ethanol Production

Table 4 sums up the specific water use ranges and averages for industrial processing of sugar cane. It considers that the sugar cane is used in the production of sugar and ethanol on a 50/50 basis (Elia Neto, 1996).

Table 4: Water uses (mean values) in mills having an annexed distillery

Sector	**Process**	**Mean use (total m3/sugar cane t)**	**Distribution**
Feeding	Sugar cane washing	5.33	25.4
Extraction (grinding)	Inhibition	0.25	1.2
	Bearing cooling	0.15	0.7
Juice treatment	Preparation of lime mixture	0.01	0.1
	Cooling sulphiting(1)	0.05	0.2
	Filter inhibition	0.04	0.2
	Filter condensers	0.30	1.4
Juice concentration	Condensers/multijets evaporation(1)	2.00	9.5
	Condensers/multijets heaters (1)	4.00	19.0
	Molasses dilution	0.03	0.1
	Crystallizer cooling (1)	0.05	0.2
	Sugar washing (1)	0.01	0.0
Electrical power generation	Steam production	0.50	2.4
	Turbo generator cooling	0.20	1.0
Fermentation	Juice cooling (2)	1.00	4.8
	Fermentation cooling (2)	3.00	14.3
Distillery	Condenser cooling (2)	4.00	19.0
Other	Floor & equipment cleaning	0.05	0.2
	Drinking	0.03	0.1
Total		21.00	100.0

Notes: (1) in sugar production only
(2) in ethanol production only

The estimates mean end use of 21m3/t of sugar cane corresponds to much lower levels of water collection, consumption and release due to water reuse. Note that about 87 percent of the uses take place in four processes: sugar cane washing; condenser/multijet in evaporation and vacuum; fermentation cooling; and alcohol condenser cooling.

With the rationing of water consumption (reuses and circuit closing, as well as some process changes, such as the reduction of sugar cane washing), water collection has been decreasing. A preliminary, limited survey conducted in 1995 (Elia Neto, 1995) in mills owned by COPERSUCAR GROUP pointed to a mean collection rate of 2.9m^3/sugar cane tonne. A more comprehensive review released in 1997 indicated that the collection was actually at 5 m^3/sugar cane t. Such a Rate is equivalent to that estimate for 1990, based on the total demand in São Paulo, which was 5.6m^3/sugar cane t. The results for water withdraw, consumption and release are shown in Table 5.

Table 5: Water withdraw, consumption and release in 1990, 1997 and 2005 (in m^3/t cane)

	1990	1997	2005
Collection	5.6	5.07	1.83/1.23(a)
Release	3.8	4.15	n/a
Net Consumption	1.8	0.92	n/a

Note: a: 1.83 m^3/t cane is the average collection of all mills in São Paulo. When the mills with the highest water consumption are excluded (8% of all mills), than the remaining 92% of the mills has an average water collection rate of 1.23m^3/t.
Source: Macedo 2005

Over the past few years, there has been more action concerning the rationalization of water consumptions and reuse, and the reduction of release levels at São Paulo-based mills. In order to examine the extent of the changes, a survey was conducted through questionnaires and interviews with a large number of mills, accounting for a total sugar cane milling of 695,000 tonnes per day (around 50% of the Center-South) production)(UNICA, 2005). The result was 1.8m^3 of water/t of sugar cane, and excluding the mills having the highest specific consumption, the mean rate for the mills that account for 92 percent of total milling is 1.23m^3 of water / t of sugar cane. These figures indicate an extraordinary advance in water handling during the period.

2. Ethanol Production – From Field to Industry

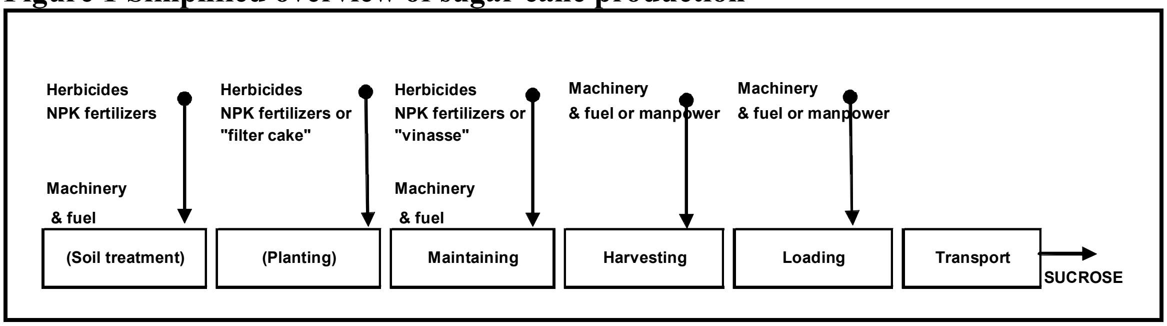
2.1 Sugar Cane Crops

Before planting in the first year, the soil is intensively prepared by, nowadays most mechanical, operations such as sub soiling, harrowing and application of mineral fertilizers. After this the soil is furrowed and phosphate-rich fertilizers are applied, seeds are distributed and the furrows are closed and fertilizers and herbicides are applied once again. The plant is furrowed and treated with artificial fertilizers or ´filter cake´[2] once or twice again during cultivation in the first year. After 12-18 months the cane is ready for the first cut. For this it is (still) common to burn down the cane in order to simplify manual harvesting[3]. Mechanical harvesting is applied by approximately 25% (CTC, 2004) of the cane in SP. Green cane harvesting is possible but the celluloid leaves have no purpose in the industry yet, so leaves are left on the field as organic fertilizer.

[2] Filter cake is a rest product of sugar and ethanol production, it contains large amounts of nutrients, which are filtered out of the juice in the sedimentation process.
[3] The field is set on fire to burn the green residues such as leaves and kill dangerous animals in the field. After burning the leaves, harvest of the sugar-containing cane stalks takes place by relatively easy manual cutting. In case of mechanical harvesting, the cane is not burnt.

Then the process starts all over again excluding intensive soil treatments and planting. Depending on the rate of the declining yields, the same stock can be used. Yields decline with approximately 15 percent after the first harvest and 6-8 percent in the years that follow. Declining yields depend on treatment of the stock during maintenance and harvesting but are mainly determined by the combination of applied variety and type of soil (Braunbeck et al., 1999). During preparation for the next season, the soil is treated less intensively but fertilizers and herbicides are heavily used. A simplified overview of the production process of sugarcane is shown in Figure 1. Processes between brackets are only necessary at the beginning of the ratoon-system.

Figure 1 Simplified overview of sugar cane production

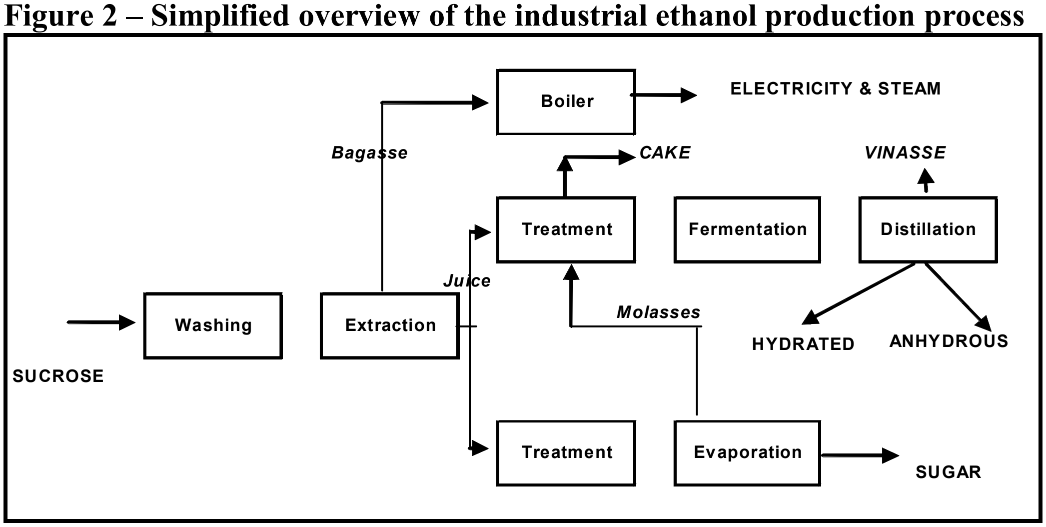


2.2 Ethanol Production

The simplified combined production process of sugar and ethanol from sugarcane is presented in Figure 2. The figure shows two kinds of ethanol, namely hydrated ethanol and anhydrous ethanol. Both are produced in large quantities, hydrated ethanol is used as a fuel for special adapted ethanol engines and anhydrous ethanol can be used to produce gasohol (mixtures of gasoline and ethanol).

The common unit for yield in the industry is [TC/ha/year], which is around 80-90 TC/ha/year in São Paulo. A more accurate unit for agricultural yields is tones of reducible sugar [TRS/ha/year].

Figure 2 – Simplified overview of the industrial ethanol production process



In summary, the cane is washed to remove organic material from the field and shredded into smaller pieces of 20-25 cm. After these pretreatments the feedstock is fed to and extracted by a set of 4-7 mill combinations into juice and bagasse (the fiber residue). The main objective of the milling process is to extract the largest possible amount of sucrose from the cane, a secondary, and increasingly important objective is the production of bagasse with a low moisture content as boiler fuel. The boilers supply enough electricity and steam for the process to be self-sufficient, in some cases even some electricity can be delivered to the grid. Next, the cane juice is filtered and treated by chemicals and pasteurized. The juice follows two different paths: a) the lower one shown in Figure 2 if the final product is sugar; b) the upper one if the final product is ethanol. For path a, before increasing the concentration of sugar by evaporation, the juice is filtered once again. The evaporation process increases the sugar concentration of the juice from 14-16°Brix up to 50- 58°Brix. The syrup is then crystallized by either cooling crystallization or boiling crystallization. Crystallization leads to a mixture of clear crystals surrounded by molasses with a concentration of 91-93°Brix. Molasses are then removed by centrifugation, and the crystals are washed by addition of steam, after which the crystals are dried by an airflow. Molasses undergoes another pretreatment including pasteurization and repeated addition of lime, which leads to a sterilized molasses free of impurities, ready to be fermented. Following path b the juice and molasses are fermented. In the fermentation process sugars are transformed into ethanol by addition of yeast. Fermentation time varies from 4-12 hours, chemical efficiencies range from 80-90%, resulting in an alcohol content of 7-10° GL, called fermented wine. The wine is centrifuged in order to recover the yeast. Making use of the different boiling points the alcohol in the fermented wine is separated from the main resting solid components; yeast, nonfermentable sugars, minerals and gasses; mainly CO_2 and SO_2. The remaining product is hydrated ethanol with a concentration of 96°GL. Further dehydration up to the required 99,7°GL in order to produce anhydrous ethanol and is normally done by addition of cyclohexane.

3. Water Impacts Due Ethanol Production

3.1 Introduction

Three stages can be distinguished in the environmental impacts: preliminary, agricultural and industrial. The first stage includes the implementation of the agro-industrial complex: land clearing, construction and implementation of the infrastructure. Only the aspects dealing with water uses are discussed in this paper.

Although the type of impacts and the ways to mitigate them are similar for any production site, most of the details in this paper are based on the situation in Sao Paulo State, where CETESB, the Sao Paulo State Environmental Technology and Sanitation Agency, has been very active in reducing the various emissions. Thus, we will discuss water impacts caused by sugar cane crops (contamination of open water systems by agrochemicals and fertilizers, contamination of groundwater by agrochemicals, fertilizer and deposition of liquid and solid residues on the soil, soil erosion**)** and for processing the crop to ethanol (Table 11 in Section 3 shows the most important wastewater flows from ethanol production and their pollution potential).

Table 6 lists the most important environmental impacts associated with the production of ethanol. The list is not comprehensive, and there is no order of importance. Impacts listed in bold are the ones dealing with water use.

Table 6: Environmental impacts of ethanol production from sugar cane

* **pollution of open water systems by industrial effluents**; * **contamination of open water systems by agrochemicals and fertilizers;** * **contamination of groundwater by agrochemicals, fertilizer and deposition of liquid and solid residues on the soil;** * **soil erosion;** * **pollution of water**, air and soil due to accidents **with transport and storage of (by)products;** * air pollution due to bagasse burning; * air pollution and inconvenience due to cane and cane residue burning; * air pollution and inconvenience due to storage and soil-application of vinasses; * **proliferation of insects due to vinasses;** * reduction of visibility on roads due to cane and cane residue burning; * deforestation; * substitution of food and other cultures; * human health effects, for both workers and local population, due to agrochemicals; * infrastructure over-use.

Sources: RIMA Batatais 1990

3.2 Agricultural Aspects

3.2.1 Monoculture and Use of Agrochemicals and Fertilizers

The sugar cane production in Brazil involves huge areas of mono-culture. This represents a complete change in the agro-ecosystem, in particular a higher incidence of pests. Therefore, larger amounts of pesticides are being employed, resulting in increased environmental problems and a higher chance of population contamination and/or labour intoxication. These problems may have been minimized by installing smaller-capacity distilleries for smaller plantations. Economies of scale, however, would have been lost to a great extent.

The agrochemicals used in sugarcane cultivation include fertilizer, herbicides, insecticides and fungicides. The required quantities of these chemicals are very site specific. Fertilizer requirements are also very dependent on the extend of vinasses application to the soil. Herbicides are used in quantities ranging from 500 to 3000 grams per ha. Insecticide use ranges from 15 to 1000 grams per ha (RIMA Batatais, 1990)

3.2.1.1 Fertilizer use

Of all crops in Brazil that cover an area in excess f 1 million hectares, sugar cane crops rank fourth on a list of 10 users fertilizer use intensity (Table 7), with 460kg of a mean formula of N-P2O5-K2O per hectare (ANDA, 2003).

Fertilizer application rates are limited compared to conventional crop production and much lower compared to pastures. The use of fertilizers for sugar cane is not perceived as a problem. However, the use of mineral fertilizers is supplemented by the use of nutrient rich wastes (vinasse) from sugar and ethanol production.

Sugar cane crops in Brazil use a low level of fertilizers compared to other countries. In Australia, the ratoon and plant sugar cane fertilization levels are 30 and 54 percent higher than in Brazil, respectively, especially in nitrogen application, with doses of up to 200kg/ha (Table 8).

Table 7: Intensity of fertilizer use in crops in Brazil

Crops	**Area (1) (1,000ha)**	**Consumption (1,000 t)**	**Consumption / area**
Year	**2003**	**2003**	**(t/ha)**
Herbaceous cotton	1,012	950	0.94
Coffee (3)	2,551	1,375	0.54
Orange (3)	823	406	0.49
Sugar cane (3)	5,592	2,600	0.46
Soybean	21,069	8,428	0.40
Corn (2)	13,043	4,082	0.31
Wheat (3)	2,489	742	0.30
Rice	3,575	872	0.24
Beans (2)	4,223	650	0.15
Reforestation	1,150	129	0.11

Notes: (1) Data from the Systematic Survey of Agricultural Production – LSPA – IBGE and CONAB

(2) These cultures total all of the harvested crops

(3) Crops planted and harvested in the same year

Table 8: Fertilizer use level in sugar cane: Australia and Brazil, k/ha

Cane stage			Plant	Ratoon
Country	Australia	N	200	200
		P_2O_5	58	57
		K_2O	120	145
		Total 1	378	402
	Brazil	N	50	100
		P_2O_5	120	30
		K_2O	120	130
		Total 2	290	260
Total 1 / Total 2 ratio (%)			1.30	1.54

Source: Adapted from CaneGrowers' 1995; CTC, 1998; Manechini & Penatti, 2000

An important, specific factor in Brazil's sugar cane crops is the recycling of nutrients by the application of two items of industrial waste, namely, vinasse and filter cake. Vinasse is now treated as a nutrient source (rather than residue), and is application has been optimized within the topographic, soil and environmental control limits.

Sugar cane productivity increases as soil fertility and water supply rise. The maximum vinasse dose produced an additional 73t/ha in six years, which is equivalent to one more harvesting season, compared to standard mineral fertilization (57-28-115kg/ha of N-P_2O_5-K_2O) (Donzelli, 2005).

3.2.1.2 Use of Agrochemicals

During the production of sugar cane and ethanol various inorganic substances are used that are potentially harmful for the environment. Three categories are discussed here: agrochemicals, disinfectants and clarifying agents.

Agrochemicals include herbicides, insecticides, fungicides, maturators, adhesive spreading agents and defoliants. An overview of the quantities of pesticides used in sugar cane and other crops is shown in Table 9.

Table 9: Consumption of fungicides, insecticides acaricides, and agricultural defensives in 1999 and 2003 in Brazil (in kg active ingredient/ha/yr)

		Coffee	Sugar cane	Citric	Corn	Soybean
Fungicides	1999	1.38	0.00	8.94	0.00	0.00
	2003	0.66	0.00	3.56	0.01	0.16
Insecticides	1999	0.91	0.06	1.06	0.12	0.39
	2003	0.26	0.12	0.72	0.18	0.46
Acaricides	1999	0.00	0.05	16.00	0.00	0.01
	2003	0.07	0.00	10.78	0.00	0.01
Agricultural defensives	1999	0.06	0.03	0.28	0.05	0.52
	2003	0.14	0.04	1.97	0.09	0.51

Source: Macedo, 2005

The consumption of agrochemicals for sugar cane production is lower than in citric, corn, coffee and soybean cropping. Sugar cane uses more herbicides per hectare than coffee and maize, less than citric crops, and about the same amount as soybeans; however the values are not very different (Marzabal et al., 2004 in Macedo, 2005). Note that the average use of some pesticides varies significantly between years. The insecticide consumption in the US in 1991 was 0.38 kg/ha for corn and 0.26 kg/ha for soybean. Yet, the total amount of agrochemicals used for the production of sugar cane can be substantial, as a significant amount of the total area in São Paulo state is used for sugar cane production. In an evaluation by the Brazilian Agricultural Research Corporation (EMBRAPA) about the impact of sugar cane production on water quality, is classified as level 1, which means "no impact" (Rosetto, 2004; Macedo, 2005). No information was found about the reason for this classification

3.2.1.3 Brazilian Legislation and Standards

The legislation related to water use that was discussed in Section 1.3.2.1 is obviously also relevant for water pollution. In addition to that, there is also legislation specifically aimed at water pollution, including emission standards. These emissions standards are not specifically for sugar and ethanol production, but the compliance of these standards are compulsory for all economic branches. The key laws and standards are:

- Federal Law 6.938 (1981) was created and defined the National Environment Policy. However, this law was applied only after the Constitution of 1988, with the creation of the Environment National System (SISNAMA) Law 8.08, in 1990. Thus the three public levels have started to work accordingly, under the coordination of the National Environment Council (CONAMA).

- For comparison, the acceptable daily intake (ADI) of formaline is 0.15 mg/kg bodyweight (WU, 2006). A person of 75 kg would need to consume over 100 kg sugar per day to reach this level

- State Environmental Law 997 (1976). This law defines clearly the way of preventing and controlling environmental pollution. At that time only water, forestry and land codes were defined, all of them outdated and controlled through generic tools. Article 18 includes the Water Pollution Emission Standards, which state that emissions from any polluting source could be only released to any water body, under the following conditions:

  I) pH: 5.0–9.0; II) Temperature: ≤ 40ºC; III) Suspended solids: maximum 1.0 ml/l in one hour, measured using an Imhoff Sediment Cone; IV) Hexane soluble compounds: maximum 100 mg/l; V) BOD5: maximum 60 mg/l; VI) Maximum concentrations of various substances. VII) Maximum concentrations for other potential hazardous substances are to be established, case-by case by CETESB;

- The use of herbicides is regulated by Law 7,802 of 1989 and further regulated by the Decree 98,816 of 1990. The legislation is complemented by Ordinances by the Brazilian Institute of the Environment and the Brazilian Sanitary Authority.

- No legislation was found on the use of fertilizers, but there is detailed legislation in Brazil on the application, storage and processing of vinasse. The following legislation regarding vinasse is available:

- National Integration Ministry (MINTER) Ordinance 323 (1978) prohibited the release of vinasse in surface fountainheads, because of the negative impact of environmental impacts on the aquatic life and surrounding vegetation as a result of the high BOD and/or low pH and/or high temperature.

- National Environment Council (CONAMA) Resolution 0002 (1984) and 0001 (1986) required studies and determination of rules on the control of effluents from ethanol distilleries, both for new units and extensions.

- State Law 6,134 (1988), article 5 requires that wastes from industrial and other activities shall not contaminate underground waters.

- Environmental Protection Agency (CETESB-state of Sao Paulo) standards. The Cetesb Technical Rule P4.231 (2005), sets:

- Sensible areas in which vinasse use remains being prohibited;
- Standards for vinasse storage according to the Rule NBR 7229 – ABNT;
- All areas formerly used for vinasse disposal (sacrifice areas) should be immediately closed, and after that they should be assessed according to procedures of Cetesb no. 023/00/C/E. Results should be compared with standards set by Cetesb no. 014/01/E and a Directive from Ministry of Health 518/04.
- For any area, it should be installed at least 4 monitoring wells according to the rule ABNTNBR13.895 and CETESB-06.100, for checking standards of pH, hardness, sulfate, manganese, aluminium, iron, nitrate, nitrite, ammonia, Kjeldahl nitrogen[4], potassium, calcium, dissolved solids, conductivity and phenols; A legal responsible contracted by/ working for the sugar mill company will then undertake the monitoring, sending the samples for examination to an accredited lab, which will determine whether the samples meet Cetesb standards.
- In case of existing monitoring drains, they can substitute wells;
- Use of geomembrane to make tanks and channels impermeable;
- Every year, up to April 2nd a plan must be presented to the CETESB containing data on the vinasse utilization for the next campaign, containing the following aspect: the maximum amount of K2O permitted to be use in one ha is 185 kg (depending on the potassium remaining in the soil), if it does not surpass 5 % of soil cation exchange capacity (CEC);

Legislation related to water pollution can be summarized as follows. Next to the legislation on water use (Section 1.3.2.1) the most important legislation relevant to water pollution deals with:

- Waste water emissions standards
- Agro-chemicals, i.e., which agro-chemicals are allowed

Existing legislation may be insufficiently enforced and/or strict to avoid further environmental degradation, but insufficient data is available to accurately quantify these impacts.

3.2.2 Contamination Due Soil Erosion

Soil erosion in sugar cane is generally limited compared to conventional agricultural crops such as corn and soybeans, although the exact difference is dependant on local conditions. However, soil losses for sugar cane may vary dramatically from 0.1 t/ha/yr to 109 t/ha/yr, depending on many factors, such as the declivity, the annual rain fall, the management and harvesting system, etc.

Compared to pastures the soil erosion rates may be higher, because of pastures generally have a much lower soil erosion rate compared to annual crops (roughly a factor 20 or

[4] Total Kjeldahl nitrogen is defined as the sum of free ammonia and organic nitrogen compounds.

higher), but no data on soil erosion rates were available that confirm this statement in the case of sugar cane production in Brazil.

Some updated studies such as the one made by De Maria and Dechen (1998), may consider effects of no-tillage techniques and also conservation practices like contoured seeding, furrowing and ripping, use of absorption terraces, non burnt straw and others. Some crops may have developed better practices than other shifting the previous picture. Other studies shows that during a 11 year test period, there was no significant effect of sugar cane production on the soil horizon thickness or physiochemical composition of the soil (CTC, 1993 in Macedo, 2005). The increase in mechanical harvesting (without trash burning) reduces soil erosion (Gandini et al., 1996 and Conde and Donzelli, 1997 in Macedo, 2005).

The increase in the share of mechanical harvesting is also an explanation for the differences in soil erosion rates. Burnt straw, buried straw and straw on the surface result in soil erosion rates of 20.2 t/ha/y, 13.8 t/ha/y and 6.5 t/ha/y and runoff of 8, 5.8 and 2.5 % of rain fall, respectively (Macedo, 2005).

3.2.2.1 Brazilian legislation and standards

Erosion is described in several articles of the Law of Environmental Crimes (Milaré, 2004). Summarising them, two main classifications are possible:

1. Direct impact: any soil degradation or contamination is considered such as a "Crime of Pollution". Law 9605/98, Article 54, defines in general terms if a given polluter caused the degradation intentionally or not (dolosus or culposus), and also if the affected site (soil or subsoil) became temporally or indefinitely unsuitable for human use.

2. Indirect impact: pollution of water bodies, flora or fauna caused by erosion in or stemming from the affected site; Deforestation, or any other human activity stemming from the affected site causing indirectly erosion is also embraced by this law.

Beyond the aspects above, penalties will vary according to the nature, intensity and reversibility of the impact. Climate data on rainfall as well as technologies available to avoid erosion are considered to determine negligence or not and thus stating appropriate penalties.

There is also legislation that indirectly affects soil erosion, particularly the legislation regulating sugar cane burning (not discussed in this paper) and the one on permanent preservation areas as discussed in Section 1.3.2.1.

The most important one is the legislation on mechanical harvesting, which allows the use of cane residues to protect the soil and reduce soil erosion and this could reduce soil erosion rates substantially.

3.2 Industrial Aspects

3.2.1 Effluents

The management of polluting effluents of alcohol distilleries in Brazil has a history of 30 years, and the situation has improved significantly since the early years of Proálcool. Although environmental controls were still very limited during the first years, major reductions in emissions have been established since then, especially with respect to the vinasses. Another important remaining problem is the burning of sugarcane fields before harvesting (Centurion and Derisio, 1992) but it has already been addressed by legislation in the state of Sao Paulo, which requires this practice be gradually eliminated up to 2025.

To illustrate the reductions that have been achieved, Table 10 shows the situation of liquid effluents of the sugar-alcohol industry in Sao Paulo State. The effluent is expressed in tonnes of total Biological Oxygen Demand per day (BOD5 to be precise; the amount of oxygen used by biological breakdown after 5 days in a standard test). Vinasses are the major contributor to these BOD values; other effluents with high BOD include washing and condenser water. Table 10 shows the potential discharge, if all effluents are discharged untreated and no recycle or reapplication is in effect. The remaining discharge is what was being discharged in open waters by 1992.

Table 10: Potential and current discharge of liquid effluents from the sugar/ethanol industry in various river basins in Sao Paulo State

River Basin	Potential discharge (t BOD/day)	Remaining discharge (t BOD/day)
Capivari	288.1	2.7
Piracicaba	1,195.8	-
Sorocaba	36.4	0.4
Médio Tietê Inferior	1,585.7	17.0
Baixo Tietê	605.6	5.8
Ver. Parciais do Paraná	108.0	-
Peixe	139.5	-
Santo Anastácio	64.8	3.9
Alto Paranapanema	109.0	20.8
Baixo Paranapanema	527.2	25.2
Pardo	1,524.1	8.7
Mogi Guaçú	2,003.5	15.6
Turvo	759.4	0.2
São José dos Dourados	79.8	-
Ver. Parciais Rio Grande	31.3	-
Aguapei	282.0	-
TOTAL	9,340.2	100.3

Source: CETESB

Table 10 indicates how significant the reductions have been. Already in 1992 only about 1% of the total potential discharge in Sao Paulo State is directly dumped in river basins. This reduction has been achieved by recycling of washing waters, recycling of process water, and, most importantly, application of vinasses to the sugarcane fields. No estimates exist on how much ends up indirectly in river basins or groundwater. When vinasses are improperly applied, run-off water and groundwater infiltration can be significant.

BOD discharges are, for easier comparison, often expressed in terms of inhabitants equivalents: the equivalent amount of domestic sewage from the average inhabitant. The international standard for this contribution is around 54 grams BOD per day per inhabitant, which is representative for the situation in Sao Paulo Sate. In the Northeast the figure is around 36 grams due to very different socio-economic conditions. The remaining discharge in Sao Paulo, therefore, still represents a city of about 2 million people, using the 54 grams BOD per day figure. The total potential discharge would represent some 173 million people, 10% more than Brazil's current population.

3.2.2 Liquid effluents

Table 11 shows a rough indication of the various liquid effluents from an alcohol distillery annexed to a sugar mill. Although the volumes and BOD contents can vary widely with process design, the relative importance of the various effluents is more or less equal for all annexed distilleries. In autonomous distilleries, the effluents from the condenser system and the evaporation stage are non-existent.

Table 11: Effluents from sugar mill with annexed distillery

Effluent	volume (l/TC)	BOD (mg/l)	T (^oC)
vacuum condenser system	10.000-30.000	10-150 (400-1000)	40-45
washing of cane	3.000-10.000	100-500 (2.000-4.000)	25-35
cooling water	1.500-5.000	-	35-45
evaporation condensates	500-650	100-800	70-80
vinasses	665-1260	6.000-25.000	85-90
washing of floor and equipment	30-100	800-1.500	25-50

Source: CTC and CETESB. Note: l/TC = litres per tonne of cane processed; figures between brackets represent closed systems and are only a very rough indication; the ranges are very significant, since modes of operation vary between different distilleries; more details on the various effluents are given in the text.

Several other, smaller liquid effluents occur, such as the washing water from the removal of crusts, and the washing water from the boiler system.
The polluting potential of these effluents is enormous, and direct discharge would be disastrous. Environmental legislation does not allow direct discharge of these effluents. The legal limits in Sao Paulo State for discharges in open water systems are shown in Table 12, and clearly indicate the need for treatment. Federal limits are similar.

Table 12: Limits on discharge in open water systems as regulated by São Paulo State Law

temperature	< 40 ^oC
BOD_5	< 60 mg/l
pH	5-9

Source: RIMA Batatais.

In addition to these discharge limits, there is a limit to the BOD level downstream of the discharge point. For medium sized rivers, this is 5 mg/l. This puts restrictions on the volume that can be discharged, even if BOD is below the discharge limits.
The vinasses does not present the largest volume, but analyzed by its polluting potential (volume x BOD) it is by far the most important effluent. The second most important effluent is the cane washing water, with a polluting potential roughly one tenth of the vinasses. Since the vinasses are so important and its treatment and alternative uses have received considerable attention, it is dealt with in a separate chapter (11). In the following, origin, characteristics and treatment and disposal methods of the other effluents will be discussed. It is already noted here that most of the effluents that are high in solids and organics (notably the cane washing water) undergo some form of separation, after which the filtrate is discharged or recycled, and the residue mixed with vinasses for consecutive treatment/utilization.
Most effluents are being reduced significantly by the increased used of recycling, particularly for the cane washing water, the vacuum condenser effluent and the cooling water. In new designs of the sugar/ethanol plants, these effluents have been reduced to virtually zero, with only a periodical discharge of relatively small volumes of highly polluted water. In existing plants, the introduction of such measures is not always an easy task, and the scope for improvements in this area is significant.

3.2.2.1 Washing of cane

The water used to wash the cane before crushing is the first liquid effluent of the process. Leaves of the cane are usually removed in the field by burning before harvest, and the tops are cut off in the field as well. Stems are transported by truck, and the solids that are attached may take up to 10% of the weight of the cane. Washing is therefore essential to avoid these solids entering the process equipment. 3 to 10 cubic metres of water are used for every tonne of cane. With the washing, some 2.5 to 3.0% of sugar is lost. Next to this sugar, the most polluting components of the washing-water are the solids that were attached to the cane. The amount is mainly dependent on the type of machinery being used for harvesting. Equipment is being developed to loose as much earth as possible on the field (Carvalho de Leite, private communication). The composition of the washing water can vary widely. An indication is given in Table 13.

Table 13: Composition of cane washing water

COD	220 – 700 mg/l
BOD	180 – 500 mg/l
Total residue	400 – 1800 mg/l
Dissolved solids	200 – 500 mg/l
Sediment solids	2.0 – 7.0 mg/l
pH	4.7 – 5.7

Source: CETESB

Treatment of the washing water can rely on physical methods to remove the solids or on biological methods to reduce the organic content (basically lost sugar). The first treatment is usually sieving and decanting after which the washing water is led into large sedimentation tanks. The water is being re-used in the washing; the solids can be applied in the irrigation/fertilizer system. Biological treatment methods are almost never used (Centurion and Desirio, 1992).

A relatively new development is the use of dry cleaning, with high pressure blowers. Although more energy intensive the volumes of water effluent would be greatly reduced.

3.2.2.2 Cooling water

Large volumes of cooling waters are required for cooling of sugarcane juice, fermentation vessels and the condensers of the distillation columns. These effluents usually present very minor problems. Although the volumes are large, the temperature is just over ambient (35-45 ^{o}C) and it usually contains no organic material or solids. Some pollution effect may occur due to corrosion of the equipment (Centurion and Desirio, 1992).

3.2.2.3 Evaporation condensates

The clear sugar cane juice is very diluted solution of saccharose and other substances. Before crystallization of the saccharose can occur, most of the water has to be removed. This is done in several stages of evaporation. The resulting condensate of these steps is not pure water: the BOD is about 780 mg/l, the total residue 140 mg/l and the pH around 7.2. Total volume is around 500 litres per tonne of cane (Centurion and Derisio, 1992).

3.2.2.4 Vacuum condensers

The final stage of evaporation is usually conducted under vacuum which is achieved by water pressure. Some sugar is lost in this stage. The condenser system consumes huge amounts of water: 12 to 16 cubic metres for every tonne of cane according to CTC, 20 to 30 cubic metres according to CETESB.

The results of the condenser system are better with lower temperatures of intake water. Therefore, the continuous availability of large quantities of cold water is highly desirable. The closed system is the most common system in the industry, with heat exchangers between the closed circuit water and the external cooling water. The periodical discharge of the closed circuit water presents a significant environmental threat, and it should therefore get a treatment similar to vinasses (Centurion and Derisio, 1992).

Typical characteristics of the condenser effluents are shown in Table 14. The figures for the closed system are only indicative, since they entirely depend on the operation period between periodical discharges of the closed circuit water. The BOD is basically sugar, and therefore not only a pollutant, but also a loss. The sugar is not economically recoverable.

Table 14: Condenser system effluents

Characterization	**open system**	**closed system**
BOD (mg/l)	132	424
sediment residue (ml/l)	0.4	0.2
pH	6.9	5.9
dissolved oxygen (mg/l)	3.6	2.8

Source: CETESB.

3.2.2.5:Vinasses

Vinasses are by far the most important liquid effluent in terms of polluting potential from both annexed and autonomous ethanol distilleries. Its acidic character, its high BOD content, and its enormous volume make its treatment the most decisive factor in the total environmental impact of an ethanol distillery. CETESB attributes 70% of the polluting potential of an ethanol distillery to vinasses, based on a volume x BOD analysis (Centurion and Derisio, 1992).

3.2.2.5.1 Characteristics

The physical and chemical characteristics of vinasses vary widely (see Table 15): they can vary in the course of the day at a particular production facility, and vary strongly between the various facilities, depending on raw material and operating conditions of the fermentation and the distillation. The most important distinction is made with respect to the fermentation feedstock; this can be pure sugar juice or molasses or a mixture of these two. Autonomous distilleries will only use pure sugar juice, while annexed distilleries will use molasses or molasses and juice, depending on the market conditions for sugar and ethanol.

Table 15: Characteristics of vinasses, depending on the fermentation feedstock

Parameter	molasses	mixture	sugar juice
pH	4.1 - 5.0	4.4-4.6	3.7-4.6
temperature (^oC)	80-100	80-100	80-100
BOD (mg O_2/l)	25000	19800	6000-16500
COD (mg O_2/l)	65000	45000	15000-33000
total solids (mg/l)	81500	52700	23700
free solids (mg/l)	60000	40000	20000
fixed solids (mg/l)	21500	12700	3700
nitrogen (mg N/l)	450-1610	480-710	150-700
phosphorous (mg P_2O_5/l)	100-290	9-200	10-210
potassium (mg (K_2O/l)	3740-7830	3340-4600	1200-2100
calcium (mg CaO/l)	450-5180	1330-4570	130-1450
magnesium (mg/MgO)	420-1520	580-700	200-490
sulphate (mg SO_4/l)	6400	3700-3730	600-760
carbon (mg C/l)	11200-22900	8700-12100	5700-13400
C/N ratio	16-16.27	16.4-16.43	19.7-21.07
organic material (mg/l)	63400	3800	19500
reducing substances (mg/l)	9500	8300	7900

Source: CETESB

Up-do-date information (Elia Neto e Nakahodo, 1995) (corresponding to current variations in must composition) on 28 mills in 1995 are summed up in Table 16. The collections were conducted in straight vinasse, i.e. with no flegmass mixture, just off the distillery. The mean vinasse flow rate was 10.85 l/ethanol 1, with a standard deviation of 2.40. The potassium content is highlighted.

Table 16: Analytical characterization of vinasse, 1995

Vinasse characterization	Units	Minimum	Mean	Maximum	Standard deviation
pH		3.50	4.15	4.90	0.32
Temperature	^{o}C	65	89	111	9.78
DBO_5	mg/l	6,680	16,950	75,330	9,953
Chemical Oxygen Demand (COD)	mg/l	9,200	28,450	97,400	13,943
Total Solids (TS)	mg/l	10,780	25,155	38,680	6,792
Total Suspended Solids (TSS)	mg/l	260	3,967	9,500	1,940
Total Dissolved Solids (TDS)	mg/l	1,509	18,420	33,680	6,488
Nitrogen	mg/l	90	357	885	177.
Total Phosphorus	mg/l	18	60	188	36.
Total Potassium	mg/l	814	2,035	3,852	804.
Calcium	mg/l	71	515	1,096	213.
Magnesium	mg/l	97	226	456	71.
Chloride	mg/l	480	1,219	2,300	417.
Sulphate	mg/l	790	1,538	2,800	514.
Sulphite	mg/l	5	36	153	32,

The volume of vinasses varies between 9.5 and 18 litres for every litre of ethanol produced; the average is 12 to 13 litres. The amount of vinasses is easily calculated from the fermentation conditions. When no recirculation is applied, the non-ethanol component of the final broth will end up as vinasses. So at a final ethanol concentration of 8.0%, the volume of vinasses will be 11.5 litres per litre of alcohol (some of this is actually flegmasses, from the second distillation column, but is usually directly blended). Several other concentrated effluents are usually added to the vinasses, but this is highly dependent on the local situation.

Treatment methods and alternative uses for vinasses

- **Direct discharge** - Direct discharge of the vinasses in open water systems was the most common practice in the early years of Proálcool. It has disastrous effects on the water quality, due to the high temperature, the high BOD level, and the high salt content. In most production locations, discharge of all the vinasses will kill virtually all biological life, and make the water unsuitable for any other use. One of the most visible impacts is the dying of fish. The high levels of organic load (and the higher temperature) will result in a significant drop in levels of dissolved oxygen, to levels that will not support fish-life.

- **Infiltration basins** – The second most important method to dispose of the vinasses in the early years of Proálcool was the use of infiltration basins, where vinasses is stored in order to infiltrate into the soil over time. Although the disastrous effect of direct discharge is avoided, there is a significant risk of soil contamination due to the relatively small area to which the vinasses is applied. In addition, chances for groundwater contamination are also high. It also requires large areas of land, which presents a loss in productive agricultural land. The basins are therefore called "áreas de sacrificio".

- **Soil application** – The practice to apply vinasses to the soil on the sugar cane fields is currently the most common practice in Brazil. This application is part of an integrated irrigation and fertilization system. Although the high contamination risk associated with infiltration basins is avoided, the method is not without negative environmental impacts. This is the most commonly used method used in Brazil.

4. Summary and Conclusions

- Even thought Brazil has the greatest availability of water in the world, with 14 percent of the surface waters and the equivalent to the annual flow in underground aquifiers, the use of crop irrigation is very small (~3.3Mha, compared to 227Mha in the world).
- Sugarcane crops are virtually not irrigated in Brazil, except for some small areas (supplementary irrigation). Efficient methods (subsurface dripping and others) are being evaluated.
- The levels of water withdraw and release for industrial use have substantially decreased over the past few years, from around $5m^3$/sugar cane t collected in 1990 and 1997 to $1.83m^3$/sugar cane t in 2004 (sampling in São Paulo). The water reuse level is high (the total use was $21m^3$/sugar cane t in 1997), and the efficiency of the treatment for release was in excess of 98 percent.
- It seems possible to reach rates near $1m^3$/sugar cane tonne (collection) and zero (release) by optimizing both the reuse and use of wastewater in ferti-irrigation.
- For the most part, environmental problems relating to water quality, which result from irrigation (dragging of nutrients and pesticides, erosion) and industrial use, are found in São Paulo. In this respect, EMBRAPA rates sugar cane as Level 1(no impact on water quality).
- The APPs relating to riverside woods have reached 8.1 percent of the sugar cane crop area in São Paulo, 3.4 percent of which having natural riverside wood restoration programs, in addition to the protection of water springs and streams, can promote the restoration of plant biodiversity in the long term.

The use of synthetic fertilizers is of little importance: the use is limited both in absolute terms as in relative terms (compared to conventional crop production). The use of vinasse as fertilizer (ferti-irrigation) is however an important source of environmental degradation, particularly in the past. The use of vinasse is closely related to the issues of water use and water pollution. Legislation has been recently been implemented aimed to avoid the negative impacts vinasse applications. Yet, additional requirements are desirable, considering the general poor law enforcement. Various well-established improvement strategies can be used to reduce the environmental impacts of energy crop production. We classify this issue as a medium bottleneck for ethanol production.

Water pollution is a serious problem in some regions in Sao Paulo state, though main pollution sources seem to be raw sewage, leaking land fills and industrial waste. The production of ethanol leads to significant amounts of wastewater, but this amount has been strongly reduced over the last years. In recent literature, we only found incidental reports of nutrient leaching and risk of pesticides form sugar cane cultivation reaching the ground water. Legislation is presently being implemented aimed at water pollution. For more strict sustainability criteria in the future, additional measures may be required, because existing legislation may be insufficiently enforced to prevent further environmental degradation. Data on these issues are however scarce.

Soil erosion during sugar cane production can be a site-specific problem. Soil erosion rates under sugar cane production are limited compared to conventional cropland, but are likely higher compared to pastures. Data on soil erosion rates under various land use types are however uncertain. Soil erosion can be prevented in various ways, although it cannot be avoided completely. Consequently, only in case very strict soil erosion rates are applied (which goes beyond the approach applied in existing certification systems and guidelines) soil erosion could be an important bottleneck for certification. As far as soil erosion can be prevented, the costs are likely in the order of magnitude of a few percent of the production costs of ethanol. We conclude that soil erosion can be regarded in general as having a medium impact factor on soil erosion.

References

ANDA, 2003: ANDA – Associação Nacional para Difusão de Adubos: Anuário estatístico do setor de fertilizantes: 1987-2003, São Paulo, 2003, pg 34)

Anselmi, R., 2004. “Irrigar é preciso”, JornalCana, ed. 124, April 2004, pp. 36-40

Barbosa, M. L., 2005 Survey carried out for UNICA, questions prepared by CTC-Centro de Tecnologia Canavieira, January.

Berndes, G., 2002. 'Bioenergy and water. The implications of large-scale bioenergy production for water use and supply', Global Environmental Change 12 (4), 253-271.

Braunbeck et al., 1999. Prospects for green harvesting and cane residue use in Brazil, Biomass and Bioenergy 17, p. 495-506.

CaneGrowers, 1995. Cane Growers’ Information Handbook 1994-95, Brisbane, Australian Canegrower, 1995

Centurion, R. and J. Desirio, 1992. CETESB, Evoluçao do controle da poluiçao das industria sucro-alcooleiras no estado de Sao Paulo, Sao Paulo, 1992

Conde, A.J and Donzelli, J.L., 1997. Manejo conservacionista do solo para areas de colheita mecanizada de cana queimada e sem queimar, VII Workshop on Agronomic Technology, CTC, Piracicaba, Brazil.

CTC, 1988, “Recomendação de adubação para a cultura de cana-de-açúcar”, Cadernos Copersucar Série Agronõmica nº 17, Piracicaba, Centro de Tecnologia Canavieira, 1988

CTC, 2004. Internal benchmark report on 15 sugar mills in the state of São Paolo.

De Maria, I.C. and Dechen, S.:1998. Perdas por erosão do solo em cana-de-açú. STAB-Açúcar, álcool e subprodutos.v.17,n.2,p.20-21,1998.

Donzelli, J.L., 2005. The use of fertilizers in Brazil’s sugar cane production in Macedo, I. d. C. et al., 2005. Sugar cane's energy. Twelve studies on Brazilian sugar cane agribusiness and its sustainability, UNICA.

Elia Neto, A., 1995. “Tratamento de efluentes na agroindustria sucroalcooleira”, presented at FEBRAL/95 – Brazil – Germany Fair, São Paulo, SP, 1995

Elia Neto, A.; Nakahodo, T., 1995. "Caracterização fisic0-química da vinhaça – Projeto n^o 9500278", Relatório Técnico da Seção de Tecnologia de Tratamento de Águas do Centro de Tecnologia Canavieira, Piracicaba, 1995

Elia Neto, A., 1996. "Workshop sobre cobrança pelo uso da água" – Convenio AIAA Comitê da Bacia Hidrográfica dos Rios Piracicabas, Capivari e Jundiaí (CBH-PCJ), Piracicaba, 1996

FAO, 2004 – FAO Data Base: Faostat, 2004

Freitas, M.A.V., 2002. Hidroeletricidade no Brasil: Perspectivas de desenvolvimento e sustentabilidade na Geração e Uso de Energia no Brasil. Os Próximos 20 anos. UNICAMP/ABC.

Gandini, M.O., Gazon, A.L., Conde, A.J.,Doneli, J.L., 1996. Conservação de solos e planejamento da sulcação em areas de colheita mecanizada de cana crua, National STAB Congress, Recife, Brazil.

Macedo, I. d. C. et al., 2005. Sugar cane's energy. Twelve studies on Brazilian sugar cane agribusiness and its sustainability, UNICA.

Manechini, C.; Penatti, C.P., 2000. "Nutrição mineral de cana-de-açúcar – novos parâmetros", Agrícola Informa no. 112, Piracicaba, Centro de Tecnologia Canavieira, 2000

Marzabal, N.E., Gastaldi, H.L.G., 2004. Demanda relativa por defensivos agricolas pelas principais culturas comerciais pos-desvalorização do Real, ESALQ-University of Sao Paulo, August.

Matioli, C.S., 1998. Irrigação suplementar da cana de açúcar: modelo de análise de decisão para o Estado de São Paulo, Piracicaba, SP, Doctor's thesis – Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, 1998

Milaré, E., 2004. Direito do Ambiente: doutrina, jurisprudência, glossário.- 3.ed.rev.,atual. E ampl. - SãoPaulo.

RIMA Batatais 1990, various Copersucar publications and private communications with Copersucar and CETESB staff members

Rosetto, R., 2004. "A cultura da cana, da degradação à conservação", Visão Agrícola, ESALQ-USP, Ano 1, Jan 2004

UNICA, 2005: Internal report (reserved), UNICA, 2005. Survey on water collection by sugar cane industry, M. Luiza Barbosa, under the assistance of Centro de Tecnologia Canavieira)

WB, 1998, Pollution Prevention and Abatement Handbook, World Bank, Washington, D.C., 471.

WU, 2006. Fact sheet on formaldehyde. Food-info site, maintained by Wageningen University, available at: http://www.food-info.net/nl/e/e240.htm